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Single-pass tillage combined with herbicides and rice stubbles enhances weed control and yield of rapeseed in Bangladesh

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Abstract

South Asian farmers are turning to mechanized planting, crop stubble retention, and herbicide application to address the current labor shortage situation. The purpose of this on-farm study was to compare conventional plow tillage combined with manual weeding to single-pass tillage combined with herbicides on the overall weed control efficacy and seed yield of rapeseed (*Brassica napus* L.) under northern Bangladesh conditions. During 2014–2016, the rapeseed variety 'BARI Mustard-14' was grown under two different tillage systems, plow tillage and single-pass tillage with zero-stubble and 50% standing stubbles of previously grown monsoon rice. The plow tillage was conducted using a two-wheel, while the single-pass tillage was performed using a versatile multi-crop planter. In plow tillage, weeds were managed by hand on three dates. In single-pass tillage, a pre-plant herbicide (glyphosate), pre-emergence herbicide (pendimethalin), and post-emergence herbicide (isoproturon) were applied for weed control. Data revealed that the combination of single-pass tillage and herbicides with 50% rice stubbles resulted in the highest weed control efficacy. Additionally, this practice resulted in a 20% yield increase and a 70% increase in benefit-cost ratio compared with plow tillage and hand weedings combination without keeping any rice stubbles in the field.

1. Introduction

Tillage has been an integral agronomic practice that directly impacts crop performance by influencing nutrient availability, water usage efficiency, and root growth and affecting the growth of weeds [1]. Tillage often provides some immediate advantages, including improved soil conditions for crop emergence, robust seedling development, increased nutrient uptake, and increased crop production [2]. Traditional agriculture, which is focused on plow tillage (PT), has been accused of causing severe results in soil crusting and compaction, accelerates soil erosion, increases soil organic matter mineralization, degrades and fractures soil aggregates, and worsens the availability of nutrients to crop plants [3]. The heavily mechanized PT has long resulted in uncovered field surfaces, decreased land productivity, significant water depletion, and an exceedingly unfavorable ecological climate that is both time and labor-intensive [4]. On the other hand, adopting reduced tillage (RT) methods such as single-pass tillage (SPT) could be an evolving strategy for global agriculture to optimize crop yields while maintaining soil properties. Furthermore, this activity delays the degradation of plant stubbles and regulates the release of mineralized plant nutrients into the soil [5].

Energy efficiency is one of the prerequisites for sustainable agricultural development. Due to the ever-rising fuel prices, energy consumption in crop production cycles has become a growing concern. Since RT takes less overall energy to produce nearly the same amount of crop as PT, it is considered more efficient due to its lower operational costs [6]. As a result, RT is becoming a more appealing choice to farmers worldwide [7].

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Weed infestation is a major obstacle facing the widespread acceptance of RT systems. Crop yields in RT can exceed that under PT if weeds are efficiently managed [8]. However, increased labor shortages in agriculture due to rural to urban relocation both inside and outside the nation [9] impact crop production globally. Labor shortages and high salaries, particularly during high-demand periods, renders hand weeding procedures economically unviable [10]. Farmers are overcoming this restriction by transitioning for a simple, efficient, and cheaper method for controlling weeds using herbicides. Former research established that knock-down, pre- and post-emergence herbicide application ensured continuous successful management of weed species that appeared through multiple cohorts and yielded higher crops than manual weeding, even when RT was used [11]. However, herbicide resistance due to the recurring use of herbicides with a similar mode of action increases the difficulty of weed control using herbicides [12]. Another serious threat is the persistent toxic effect of herbicide on the next crop in the rotation cycle [13]. Thus, it is essential to implement advanced integrated weed control techniques to improve crop development productivity with RT. Agronomic practices such as stubble retention of previous crops have been reported to limit weeds growth [14], ameliorating the use of herbicides and limiting their toxicity on following crops.

Single-pass operated strip tillage (SPT) is one of various RT-based reduced soil disrupting solutions[15] that entails tilling only 6 × 4 cm in depth and width, occupying 15-25% of the soil area [16]. Rapeseed cultivation under SPT system with stubbles retention of previous crops is investigated in Bangladesh. However, the optimal method of weed management has not been achieved. Therefore, this research was carried out in Bangladesh to address the influence of residual retention, tillage, and weed control methods on the productivity and weed control efficacy in *Brassica napus* L cultivation systems.

2. Materials and Methods

2.1. Site and tenure of the study

A monsoon rice-rapeseed-winter rice crop sequence experiment was carried out on-farm at the Gouripur area of Bangladesh (N: 24 75' and E: 90 50') during 2014-15 and 2015-16 seasons.

2.2. Soil and atmosphere

The experiment site is located on the Old Brahmaputra Floodplain, which is primarily composed of dark grey non-calcareous alluvium soils. The experimental area was a flood-free medium-high land with a sandy clay loam texture (sand, silt, clay at 50, 23, and 27%, respectively) and pH 7.2.

November was the warmest month during the experiment, with maximum temperatures of 29.9 and 30.0°C and minimum temperatures of 18.07 and 18.1°C in the 1st and 2nd year, respectively (Table 1). From November to January, the temperature steadily decreased. January was the coolest month of both years. November 2014 and December 2015 were the driest months. In both years, the maximum rainfall of 20 mm, occurred in February. November and December were the months with the most and least sunlight hours, respectively, in both years.

Table 1. Monthly average temperature, total rainfall, and sunshine distribution pattern in 2014 – 2016.

	Nov-14	Dec-14	Jan-15	Feb-15	Nov-15	Dec-15	Jan-16	Feb-16
Max. Temp. (°C)	29.9	23.88	23.9	26.8	30	25.2	23.8	28.2
Min. Temp. (°C)	18.07	13.62	13.5	15.6	18.1	13.3	12.02	16.8
Rainfall (mm)	0	0	14.9	19.6	4.3	0	15.2	19.4
Sunshine (hrs.)	215.4	123.69	132.5	122.2	200	117.9	132.5	122.2

Max.: Maximum, Min.: Minimum, Temp.: Temperature

2.3. Study material, treatments, and design

The present study deals with rapeseed variety ‘BARI Mustard-14’ (*Brassica napus* L.) grown in 2014-15 and 2015-16 calendar on the same field using two tillage methods and two levels of stubbles of monsoon rice as mentioned below. The treatments were laid out in a Randomized Complete Block Design in four replicates, with plots (9 × 5 m each) divided according to stubbles quantities.

Factor A: Tillage regimes

i. Plow tillage (PT) + manual weeding

ii. Single-pass strip tillage (SPT) + herbicide application

Factor B: Rice stubbles

i. S_0: Zero-stubbles

ii. S_{50}: 50% stubbles (50% by the height of previous monsoon rice)

A two-wheel tractor was used to cultivate the plots for plow tillage (PT). Four plowings and cross plowings were used to prepare the field, which was then sun-dried for two days before being leveled. Sigle-pass tillage (SPT) was accomplished using a versatile multi-crop planter. Strips for four rows, each six cm broad and five cm long, had been prepared. Glyphosate was also applied at 3.7 L ha^{-1} three days before SPT [16].

The zero-stubble procedure involved seeding without holding rice straw, while the 50% stubble practice included harvesting the previous monsoon rice leaving 50% of the rice plants standing in the respective plots.

On November 20 of both years, 7 kg seeds ha^{-1} were planted in rows 30 cm apart in PT and SPT. Seeds were manually sown in PT, and continuous line sowing with the versatile multi-crop planter was performed in SPT. The soil covering of seeds was done shortly after planting.

Hand weeding was performed thrice in PT at 25, 45, and 65 days after seeding (DAS). In SPT, a pre-plant (Glyphosate at 3.7 L ha^{-1}), pre-emergence (Pendimethalin at 2.5 L ha^{-1}), and post-emergence (Isoproturon at 1.25 kg ha^{-1}) herbicide applications at 3 days before seeding, immediately after seeding, and 25 DAS, respectively. A manual backpack sprayer was used to spray herbicides. All the herbicides were applied at the field capacity moisture content of the soil.

As a basal dosage, the crop was fertilized with 60 kg ha^{-1} N, 40 kg ha^{-1} P_2O_5, and 30 kg ha^{-1} K_2O. The required amounts of nitrogen, phosphorus, and potassium were supplied through urea, single superphosphate, and muriate of potash, respectively. To ensure a healthier harvest, prescribed cultural activities and plant protection mechanisms were followed.

2.4. Measurements

Weed densities (plants m^{-2}) were measured at 25, 45, 65, and 85 DAS in a 0.50 × 0.50 m quadrat. Four randomly placed quadrats in each plot were assessed. Weed biomass (g m^{-2}) was assessed after oven drying at 70 °C for 72 h. The following formula was used to determine weed control efficacy:

$$\text{weed control efficacy} = \frac{DWC-DWT}{DWC} \times 100 \qquad [17]$$

where DWC and DWT denote the dry weight of weed at control and treatment, respectively.

Visual assessment of phytotoxicity of herbicides was performed following the grading of IRRI [18].

On February 10 of each year, rapeseed was harvested when 80% of the siliqua turned brown from three randomly chosen 3 × 1 m patches each. Furthermore, plant population, number of siliquas per plant, and siliqua length (cm) of 10 randomly selected plants were recorded before harvest. The weight of 1000 seeds and the seed yield were calibrated at 14% moisture.

The crop production finance was evaluated using the partial budgeting method. The variable costs were estimated dependent on the amount of labor and other input costs required for all cultural activities from seeding to harvest. The marginal returns were determined using crop yield and market prices for byproducts. Deducting the variable expense from the total recovery yielded the gross value. The benefit-cost ratio (BCR) was estimated using the following equation

$BCR = \frac{TR}{TCP}$ [19] Where TR and TCP denote total returns and total cost of production, respectively.

2.5. Statistical analysis

The analysis of variance was performed on the data at $p \leq 0.05$ level. Duncans' Multiple Range Test was used to isolate treatment means. The regression analysis was done to study the relationship between weed biomass and rapeseed yield. All data were analyzed using the analytical kit *STAR* [20].

3. Results

3.1. Effect of tillage and residue levels on weed density, biomass, and weed control efficacy

The interaction effect of treatments exerted a significant effect at $p \leq 0.05$ on weed density (plants m^{-2}), biomass (g m^{-2}), and weed control efficacy (WCE) at all sampling dates (Table 2). The PT resulted in higher density and biomass than SPT at all assessment dates. 40 and 70% less density and biomass, respectively, were recorded in SPT compared to PT. The retention of 50% stubbles decreased weed density and biomass by 20 and 34%, respectively, compared to zero-stubbles.

Table 2. Effect of tillage method and rice stubbles on weed density, biomass, and weed control efficacy at different dates of rapeseed growth during 2014-2016.

			Weed density (plant m^{-2})		Weed biomass (g m^{-2})		WCE (%)	
			1st yr.	2nd yr.	1st yr.	2nd yr.	1st yr.	2nd yr.
25 DAS	PT	S_0	34a	39a	22a	29a	0	0
		S_{50}	29b	32a	18ab	25a	18	13
	SPT	S_0	27b	22ab	12bc	12b	45	57
		S_{50}	24c	20bc	10b	9b	55	67
STDV.			4.2	8.9	5.5	9.7		
CV (%)			14.7	31.4	35.5	52.0		
45 DAS	PT	S_0	80a	80a	33a	35a	0	0
		S_{50}	68b	76ab	24b	33a	27	6
	SPT	S_0	15c	35c	7c	9b	79	74
		S_{50}	11cd	21cd	4cd	8b	88	77
STDV.			35.6	29.5	13.8	14.8		
CV (%)			81.8	55.6	81.4	69.4		
65 DAS	PT	S_0	48a	33a	49a	57a	0	0
		S_{50}	44ab	27b	42b	53a	14	7
	SPT	S_0	25c	14c	18c	13b	63	77
		S_{50}	14d	9c	14cd	8b	71	86
STDV.			16.0	11.1	17.3	25.8		
CV (%)			48.9	53.7	56.4	78.9		
85 DAS	PT	S_0	20a	16a	19a	13a	0	0
		S_{50}	18b	13ab	10b	7b	46	44
	SPT	S_0	6c	8c	5c	4b	74	73
		S_{50}	5c	4c	2c	3b	89	78
STDV.			7.8	5.3	7.4	4.5		
CV (%)			64.1	51.9	82.7	66.7		

DAS: Days after seeding, 1st yr.: 2014-15, 2nd yr.: 2015-16, PT: Plow tillage, SPT: Single-pass tillage, S_0: Zero-stubble, S_{50}: 50% stubbles, WCE: Weed control efficacy, STDV.: Standard deviation, CV: Co-efficient of variance. For similar assessment dates, means preceded by the same letter did not vary significantly at $p \leq 0.05$.

SPTs with or without stubbles reached an average of 78.5% WCE in both years at 85 DAS (Table 2). The lowest WCE was obtained when PT was used without stubble. None of the herbicides exhibited visible phytotoxicity against rapeseed (data not shown).

3.2. Effect on the yield and benefit-cost ratio (BCR)

The SPT generated the highest seed yield in both years under both stubble levels compared to PT (Fig. 1). The 18% increase in yield in SPT is attributed to the 4% and 6% increases in plants and siliqua m^{-2}, respectively (data not shown). Among the treatment combinations, preservation of 50% stubbles resulted in a 3% increase in siliqua and a 4% increase in seed yield compared to zero-stubble.

The highest profitability (BCR) over two years was recorded under SPT with 50% stubble (Fig. 1), followed by the same treatment without stubble. SPT combined with 50% stubble resulted in a 70% BCR increase compared to PT without stubble. Overall, stubbles raised BCR by 10% compared to no-stubble; however, this increase was only significant in the second year between SPT with zero stubbles and SPT with 50% stubbles. The lower returns in PT are attributed to rapeseed's higher production costs and lower seed yield.

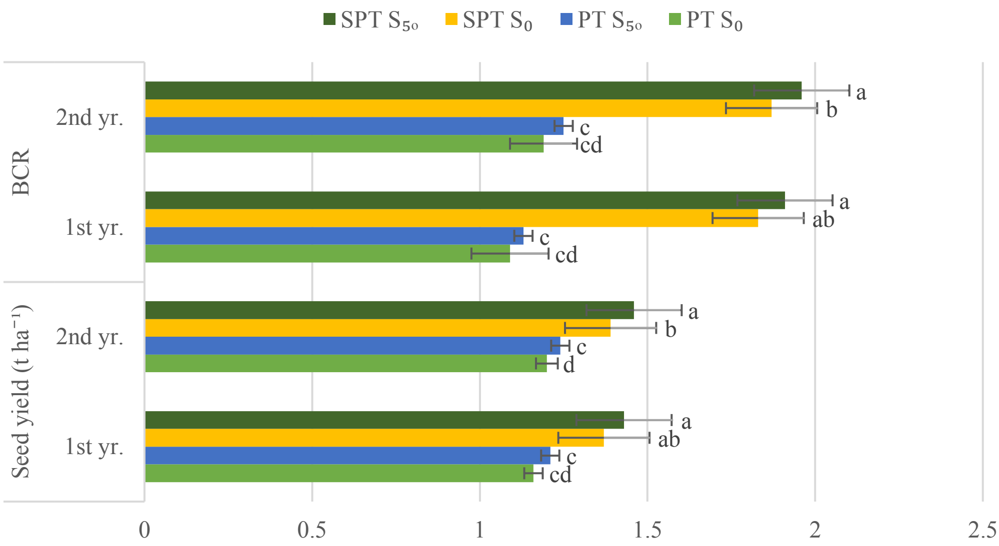

Figure 1. Effect of tillage method and rice stubbles on rapeseed yield (t ha^{-1}) and BCR during 2014-2016. 1st yr.: 2014-15, 2nd yr.: 2015-16, PT: Plow tillage, SPT: Single-pass tillage, S_0: Zero-stubble, S_{50}: 50% stubbles. In each year, means preceded by the same letter did not vary significantly at *p≤0.05*.

3.3. Regression analysis between weed biomass and rapeseed yield

The analysis of regression between weed biomass (mean across tillage types) and rapeseed yield revealed a strong negative correlation at different assessment dates (Table 3). This result indicates that a 1 kg increase in weed biomass at 25, 45, and 65 DAS resulted in rapeseed yield loss by 4.74, 2.95, and 2.12 kg ha^{-1}, respectively in the 1st year and 3.81, 2.31, and 1.47 kg ha^{-1}, respectively, in the 2nd year.

Table 3. Analysis of regression between weed biomass and rapeseed production.

Time of evaluation	1st year		2nd year	
	Regression equation	R^2	Regression equation	R^2
25 DAS	y= -4.74x + 4183.5	0.67	y= -3.81x + 4435.3	0.59
45 DAS	y= -2.95x + 3961.1	0.62	y= -2.31x + 4121.1	0.63
65 DAS	y= -2.12x + 4107.7	0.70	y= -1.47x+ 4139.0	0.84

Note: DAS= Date after sowing, y= seed yield of rapeseed (kg ha^{-1}), x = biomass of weeds (kg ha^{-1}), R^2= Regression co-efficient

4. Discussion

4.1. Weed density, biomass, and weed control efficacy (WCE)

In this research, PT without stubble resulted in the highest weed density and biomass. Simultaneously, the lowest weed density and biomass occurred in SPT combined with the application of glyphosate herbicide, followed by one pre-emergence (pendimethalin) and one post-emergence herbicide (isoproturon) with 50% stubble. PT offers a preferable sprouting medium for the growth of most weed seeds since more oxidized and warmer soil is produced by the significant soil pulverization [21]. Furthermore, tilled soils often act as a germination stimulus for weed seeds that need scarification, elevated CO_2 levels, increased nitrate levels, and temperature fluctuations to break dormancy [22], resulting in increased weed emergence and density in PT.

Reports show that around 75% and 11% of weed seeds are deposited in the surface soil layer in SPT and PT soils, respectively [23]. Weed seeds on or near the soil surface might lose viability due to drying and extreme weather conditions, resulting in increased non-viable weed seeds and a lower weed density in SPT than PT [24]. Additionally, the lower weed density in SPT may be due to the lethal germination of weed seeds. The radicle of germinated weeds may have trouble penetrating the soil surface in SPT [25]. As a result, the weed plant's growth, development, and seed production are halted, explaining why SPT had a lower weed density and lower weed biomass than PT in this research. Reduced weed mass in SPT may also be connected with weed seed predation by birds, soil insects, rodents, and diseases [26] since it increases seed availability to predators and lowers predator mortality [27].

In the current study, hand weeding might result in greater weed density in PT since some weeds escaped the three manual weeding processes. The SPT, alternatively, was treated with glyphosate, pendimethalin, and isoproturon herbicides. These chemicals successfully managed weeds, resulting in SPT having a lower weed density and an 80% higher WCE than hand weeding of PT. Massive action and greater herbicide phytotoxicity [28][29] to almost all weed types may illustrate a greater WCE in SPT than PT.

4.2. Effect on the yield

Increased yield in SPT versus PT might be a result of reduced weed plants and mass m^{-2} area. Due to an inverse relationship between weed infestation and crop production, and it has previously been stated that crop yield is even more significant in the reduced tillage than in the conventional method when weeds are effectively managed [30][31]. The greater weed infestations in PT might result in lower rapeseed yields due to increased crop weed competition. Weeds fight for soil nutrients, light, and space [32] and exude phytochemicals [33], resulting in a yield loss in PT where manual weeding was used since weed pressure and crop yield are inversely related [34].

As seen in (Table 3), growing one kilogram of weed biomass in each assessment date led to a considerable reduction in the later rapeseed yield. The regression analysis results indicate that 25 DAS is the most crucial phase for weed control in rapeseed production regardless of the used tillage system. Herbicide-treated plots in SPT, with fewer weeds, developed more siliqua and filled seeds, resulting in higher yield.

Results of some previous studies revealed that herbicides sprayed at field rates also have a hormetic impact on crop growth and development, which may have contributed to the improved rapeseed yields. Glyphosate may promote plant growth, stimulate shikimic acid buildup, enhance photosynthesis and stomatal opening, all of which result in higher seed output by shortening the plant life cycle [35]. Plant defenses against pathogens may be triggered by glufosinate and protoporphyrinogen oxidase herbicides. Herbicides such as dicamba, 2,4-D, and triazine promote plant growth and crop yield [36]. Furthermore, the herbicide Dual Gold 960 EC produced the tallest plants and the maximum maize yield [37]. Increased potato yield was found due to increased N, P and K uptake influenced by metobromuron, metribuzin and chlomazon herbicides [38]. Moreover, carfentrazone-ethyl + isoproturon was found to produce more productive tillers of wheat [39].

In this analysis, 50% stubble (average across tillage types) increased grain yield by 4% as compared to no stubble. The higher plant population and numbers of siliqua m^{-2} could be attributed to the beneficial effect of crop residues. This finding is in line with the results of [40], who recorded a significant increase in the average crop yield by 5% under crop residue maintenance compared to no-straw treatment. Mungbean yield was increased by 5% in 50% residue

over no residue in Bangladesh [41]. Additionally, a 3% higher rice yield [42] and 4% higher wheat yield [43] were recorded in 50% stubble mulch compared to no-stubble. Increased crop residue retention enhances soil porosity, reduces soil compaction and bulk density, and increases soil aeration and water status productivity [44]. Furthermore, crop residues enhance the organic matter, accessible minerals, fulvic acid, and humic acid levels of the soil and facilitate the release of slow-acting potassium [45], consequently lowering the need for artificial fertilizers [46], improving the soil environment [47], increasing the leaf area of plants, and enhancing photosynthetic material transfer to the grain [48], thus, increasing crop production and quality [49]. Crop residues are high in organic matter, which may serve as a carbon source for soil microorganisms, stimulate microbial activity, enhance soil fertility [50], encourage earthworm reproduction, and increase the variety of soil arbuscular mycorrhizal fungi [51][52], thus improving crop yield.

4.3. Effect on the benefit-cost ratio (BCR)

BCR variance may be due to variations in grain yield and main input costs, namely land planning, weeding, and labor requirements for rapeseed cultivation in PT and SPT. In this study, land preparation costs were US$ 35.3 ha^{-1} in SPT but 65.0 ha^{-1} in PT. Hence, SPT saved about 45% of land preparation costs compared to PT. This finding is in line with a previous study where around 67% savings on land preparation costs in RT (US$ 35.8 ha^{-1}) in comparison to conventional tillage (US$ 190.8 ha^{-1}) owing to single plowing and lesser amount of diesel/ gasoline usage [53]. [54] reported a 68% cost savings for plowing in ST as compared to PT, where SPT incurred a cost of US$ 33.65–38.46 ha^{-1} against US$ 81.73–144.23 ha^{-1} in PT. Furthermore, 49% of savings were calculated when SPT was used instead of PT for land plowing [55].

Utilizing herbicides to manage weeds under SPT resulted in higher net benefits compared to the hand weeding operations under PT. Three manual weedings were needed in PT, costing US$ 313.28 ha^{-1}. By comparison, herbicides (glyphosate, pendimethalin, and isoproturon) incurred only US$ 134.29 ha^{-1}. Consequently, compared to manual weeding in PT, herbicidal weed control in SPT saved 57% in cost. Additionally, previous studies indicated that the higher costs associated with manual weeding were unprofitable compared to herbicidal weed control [56][57]. The current research estimated that 771 person-days ha^{-1} of labor was needed for rapeseed cultivation (from seeding to seed storage) in the PT practice compared to 584 person-days ha^{-1} in SPT. As a result, relative to PT, SPT lowered labor requirements by 25%. This reduction allowed SPT to earn a higher return than PT. This observation is consistent with previous research indicating that needed labor can be reduced by one-third due to SPT practices compared to PT [58][59][60].

5. Conclusion

Single-pass tillage proved to be more profitable in terms of yield and BCR than plow tillage for rapeseed cultivation. Glyphosate herbicide was used to combat weeds prior to single-pass tillage, supplemented by pendimethalin and isoproturon herbicides and the preservation of 50% stubble of the previous cultivated rice crop in combination with single-pass tillage.

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